DEGREE OF COOPERATIVENESS OF TERMINALS AND THE EFFECT ON THE BARGE HANDLING PROCESS

A.M. Douma[a], P.C. Schuur, R.G.M. Jagerman

University of Twente, Department of Operational Methods for Production and Logistics

[a] a.m.douma@utwente.nl

ABSTRACT
We consider the container barge rotation planning and quay scheduling problem in the Port of Rotterdam, introduced in Douma et al. (2008). The problem concerns the alignment of barge rotations (sequence of terminal visits) with the quay schedules of the terminals concerned. Douma et al. (2008) propose an agent based solution to meet the specific business constraints. Underlying assumption of their model is that terminals are fully cooperative, i.e., they make agreements with barges about guaranteed waiting times and provide insight in the terminal occupation during the day. In practice, however, terminals might behave more opportunistically. We compare different degrees of cooperativeness. Results indicate that fully cooperativeness results in the lowest average waiting time per barge and thus offers the best service to the barge. Providing less information or processing barges first-come first-served (FCFS) results in uncertain sojourn times for barges, uncertain arrival times at terminals, and increasing delays for barges. The insights we provide can help terminals to decide on the strategy they will adopt.

Keywords: cooperativeness, Multi-Agent System, quay scheduling, rotation planning

1. INTRODUCTION

We consider the container barge rotation planning and quay scheduling problem in the Port of Rotterdam. This problem was introduced by Douma et al. (2008) and concerns the alignment of barge rotations (a sequence of terminal visits) with the quay schedules of the terminals concerned. In this introductory paper an agent based solution was proposed to deal with the specific business constraints in the problem. A basic underlying assumption is that terminals are fully cooperative in the sense that they are willing to make guaranteed agreements with barges about maximum waiting times and that they give insight in their occupation during the day. However, in practice the attitude of terminals might be less cooperative, e.g., terminals might not keep the agreements with barges or give limited insight in their occupation. Aim of the present paper is to provide insight in the effect of the degree of cooperativeness of terminals on the barge handling process.

In Section 2 we describe the problem and problem setting. In Section 3 we discuss some related literature. Section 4 describes briefly the multi agent based solution proposed by Douma et al. (2008). In Section 5 we discuss the different degrees of cooperativeness of terminals. Section 6 describes our simulation model and the experimental settings. In Section 7 we present the results of the simulations. Finally, in Section 8 we discuss our results and draw some conclusions.

2. PROBLEM AND PROBLEM SETTING

The container barge rotation planning and quay scheduling problem we consider in this paper is inspired by a real problem in the Port of Rotterdam. Barges are used as means to transport containers from the port to the hinterland and vice versa. In 2007 there were 31 container terminals in the Port of Rotterdam and about 75 barges visit the port daily, visiting about eight terminals each.

For both barges and terminals it is beneficial to align their operations. For barges this is important since they want to leave the port in time, i.e., in accordance with their sailing schedule. For terminals this is important to use their quays as efficiently as possible.

Complexities in the problem are the specific business constraints. In the past, several attempts have been made to establish a central party that coordinates the activities of both terminals and barges. However, it turned out that this solution was not acceptable for the actors involved for several reasons. First, terminal operators compete with each other (so do barge operators) and are therefore reluctant to share information that possibly undermines their competitive position. Second, no contractual relationships exist among barges and terminal operators. This means that barge operators and terminal operators cannot force each other contractually to deliver a certain service or charge each other for poor services. Third, both barge and terminal operators want to stay autonomous, i.e., in control of their own operations. Modeling the problem in a mathematical way is a hard task, since one has to deal with different actors having different interests, a highly dynamic environment (barges arrive over time, lot of events and disturbances), and a lowly structured and loosely coupled network of actors.

Today, barges and terminals communicate by means of telephone, fax, and E-mail, to make appointments. However, due to a poor alignment of activities, uncertainties during operations, and strategic behavior of both terminals and barge operators, this leads to inefficient use of quays and long sojourn times of barges in the port.

3. RELATED LITERATURE

The container barge rotation planning and quay scheduling problem has been studied before in a few studies (see, e.g., Connekt 2003; Melis et al. 2003; Schut et al. 2004; Douma et al. 2008). Besides that the problem is related to several fields. We mention the berth allocation problem (Cordeau et al. 2005; Stahlbock and Voss 2008), the ship routing and scheduling problem (Christiansen et al. 2004), the attended home delivery problem (Campbell and Savelsbergh 2006), the hospital patient scheduling problem (Decker and Li 2000), and multi agent theory (Wooldridge and Jennings 1995). In Douma et al. (2008) we provide a discussion of each of these fields. For the role operations research methods play in the in the optimization of terminals operations we refer to an extensive literature study by Steenken et al. (2004) and Stahlbock et al. (2008).

A new element in the present paper is the concept of *degree of cooperativeness*. In the literature on Multi-Agent Systems the concept *cooperation* has been frequently discussed in different meanings. Cooperative agents are, e.g., considered as agents working together to achieve the same goal, in contrast to agents that are self-motivated and maximize their own benefits (Kraus 1997). Sandholm (1999) state that self-interested agents can be assumed to be cooperative, if they use the strategies imposed by the designer and not choose a strategy themselves. The latter might be more likely in problems with competing self-interested agents. In these situations the design of the communication protocol becomes important, to let the agents exhibit desired behavior (Sandholm 1999). The concept *cooperation* in Multi-Agent Systems is also strongly related to the field of (Cooperative) Game Theory. In a game (self-interested) players usually have a choice to adopt a cooperative attitude or not, and they make a decision based on expected pay-offs. This choice might be in favor of being cooperative, especially when players have long-term relationships and face each other in repeated games (see, e.g., Mailath 2006).

The long-term relationships between terminals and barges might influence the decisions both actors make and the service they are willing to offer. It turns out that in the problem we consider the behavior of terminals is hard to regulate within the system (see Section 5 for an explanation). However, if terminals offer better services to barges, it might improve their relationship in the long term. Services can be, e.g., guarantees on waiting times (Kumar 1997; Whitt 1999).

In this paper we give insight in the effect of different degrees of cooperativeness of terminals and the effect on the barge handling process. The results can be used by terminal operators to decide which degree of cooperativeness they should adopt when implementing a Multi-Agent System.

4. MULTI AGENT BASED APPROACH

In Douma et al. (2008) we introduced a multi agent based solution for the problem. In this solution every barge and every terminal is equipped with a software agent acting in the best interest of its principal and it is assumed that every agent is opportunistic and makes the best decisions possible (in terms of the actor's objective) with the knowledge it has.

As a communication mechanism between barges and terminals we introduced an information exchange protocol based on waiting profiles. A waiting profile contains information about the maximum amount of time a barge has to wait until its processing is started after it has arrived. This information is provided for every possible arrival moment during a certain time horizon. A waiting profile is generated by a terminal on request of a barge as it enters the port and is barge specific. Waiting profiles are issued - only once per rotation - by all terminals the barge has to visit. The maximum waiting times determining the waiting profile are guaranteed maximum waiting times. This is a service to the barges such that they can accurately estimate the latest arrival time at the next terminal. The barge in turn needs to be at the terminal at the announced time, otherwise it has to make a new appointment and builds up a bad reputation which can be used by a terminal as input for the generation of future waiting profiles. The information in the waiting profiles can be used by a barge operator to determine the rotation with the smallest sojourn time in the port.

We define an *appointment* made between a barge and a terminal as an agreement from two sides. The barge promises the terminal to be present at the terminal before a certain time, i.e., the latest arrival time. The terminal in turn guarantees the barge a latest starting time, if the barge keeps its promise. If the barge does not keep its promise and arrives later than the announced time, it has to make a new appointment. In making appointments, the barge uses the guaranteed latest starting times at preceding terminals.

In Douma et al. (2008) we propose to add some slack s to the waiting profile. This means that we uniformly increase the maximum waiting times with a certain amount of time s in order to enhance the planning flexibility of terminals. In this way terminals have more possibilities to schedule barges dynamically, without violating appointments made with other barges.

To understand how waiting profiles can be generated we refer to Douma et al. (2008). For now we assume that terminals can issue waiting profiles and that a barge is able to determine a sequence of terminal visits (a rotation) that minimizes its sojourn time in the port.

5. DEGREE OF COOPERATIVENESS

In this section we introduce the concept 'degree of cooperativeness' and we describe the different degrees.

5.1. Three degrees of cooperativeness

In the multi agent based model proposed in Douma et al. (2008) we assume the terminals to be 'fully' cooperative. What we mean is that terminals give barges first a waiting profile (expressing the maximum waiting times during a certain time horizon) and, second, make appointments which guarantee barges a maximum waiting time until the start of service. In the current situation, however, terminals have a dominant position in the port. For a terminal it is of little importance that a barge has to wait a few hours. Terminals can even benefit from long queues, since this reduces their risk of quay idle time. This is not in the interest of barges, but in the current situation they have no power base to force a terminal to behave differently. The terminals on the other hand can force barges to show desired behavior, by refusing their processing and let them wait some additional time to be processed. Currently, there are several initiatives (i.e., Approach I (Connekt 2003)) to seduce terminals to be more cooperative towards barges. It would be interesting to investigate to what extent increasing cooperativeness would influence the barge handling process.

In this paper we therefore consider the effect of the 'degree of cooperativeness' of the terminal on the performance of the terminals and barges. With degree of cooperativeness we mean the extent to which i) a terminal gives insight in its occupation during the day and ii) the extent to which a terminal is willing to keep an appointment. We consider three degrees of cooperativeness:

i. Fully cooperative: a terminal issues waiting profiles and processes barges according to the appointments made
ii. Partly cooperative: a terminal issues waiting profiles, but processes barges first-come first-served
iii. Lowly cooperative: a terminal only gives insight in its current queue length, and processes barges first-come first served.

In i and ii we assume that waiting profiles are issued only once per rotation. In iii, however, the queue length is issued at any moment a barge asks for it, even repeatedly. One might argue that in case iii terminals are not that un-cooperative, since they provide information at any moment a barge asks for it. We still stick to the label 'lowly cooperative' for two reasons. First, the quality of information is low (only the current queue length). Second, this label can also be used in the case of absolute lack of terminal information, provided that barges are learning about queue lengths by other means such as barge transponders, eye-sight or friendly colleagues.

We evaluate the effect of different degrees of cooperativeness by means of simulation. We give insight in the effects of the terminal behavior on the average waiting times at the terminal, and average tardiness of a barge. Note that we fix the capacity of terminals in our experiments, which means that the utilization of the terminal is depending on the number of arriving barges and not on the degree of cooperativeness of the terminal. The latter, however, can have an effect on the average waiting time of barges in the queue.

5.2. Terminal are fully cooperative

The fully cooperative case is extensively described in Douma et al. (2008). In Section 4 we give a brief description of the idea.

5.3. Terminals are partly cooperative

If a terminal is partly cooperative it issues a kind of waiting profile which can be used by barges to determine their best rotation. However, the waiting times expressed in the waiting profile are not guaranteed. On the contrary, barges are processed in the order they arrive at the terminal.

Barges plan their rotation on arrival in the port and use the waiting profiles to minimize their expected sojourn time in the port. Once they have determined their best rotation they announce their expected arrival time to the terminal, assuming that the waiting times in the waiting profile are valid maximum waiting times. However, during execution waiting times might be different from what is announced, since other barges might have arrived earlier. Waiting profiles are therefore not more than an indication of the busyness of the terminal during certain periods of the day. The announced expected arrival times of the barges are therefore also not more than an indication, subject to the waiting times at terminals during the rotation.

Barges do not update their rotation during execution, but visit the terminals in the sequence determined on arrival of the port.

5.4. Terminals are lowly cooperative

If terminals are lowly cooperative they give only insight in the current length of their queue, e.g., as the sum of the expected processing times of the queued barges.

Barges sail through the port from terminal to terminal and make a decision on so-called decision points they visit going from one terminal to another. Barges make decisions based on information about the actual state of the port, like queue lengths of terminals they have to visit.

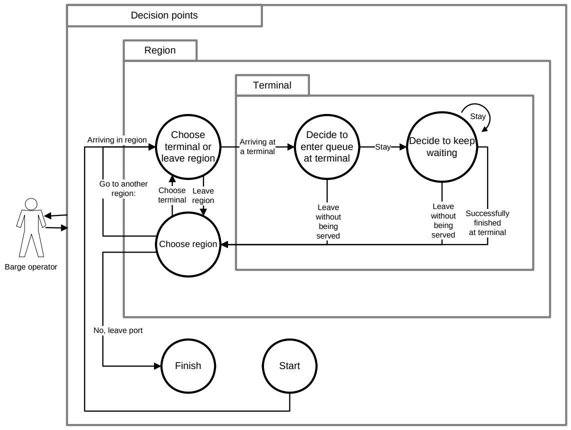

Figure 1 Decision moments for a barge operator agent in the lowly cooperative case

We define decision points at three levels, namely port level, region level, and terminal level (see Figure 1). We discuss the decision points successively. The first decision is made at node *start*, on arrival in the port. The barge operator agent first chooses which region (cluster of terminals) it wants to visit. On arrival in this region it either decides to pass the region or to visit a terminal (node *choose terminal or leave region*). If it decides to visit a terminal, the barge operator can decide, on arrival at the terminal, to enter the queue (node *decision to enter queue at terminal*). If it enters the queue it can reconsider from time to time whether it keeps on waiting at the current terminal or leave the queue to visit another terminal (node *decide to keep waiting*). After it has visited a terminal it can decide to go to another region or to stay in the current region (node *choose region*). If it decides to stay in the current region, the agent has to choose which terminal to visit or yet sail to another region. If it has decided to go to another region it sails there and on arrival in this region it again has to decide either to visit a terminal or to go to another region.

In our model we assume that barges in node *decision to enter queue at terminal* and *decide to keep waiting*, always decide to enter the queue and to keep waiting, respectively. At the node *final* the barge just decides to leave the port. At the other nodes we make a decision as denoted in Table 1. In future study we can refine the decision rules.

Note that the network of decision points is a virtual network. If we say that a barge heads to the region of the first planned terminal, this actually means that the barge first determines what the next region is. If this is the same region as it is in now, then it directly sails to the next planned terminal. If this region is different, then is will physically move to the other region and decide (on arrival in this region) which terminal to visit.

Typical for the lowly cooperative case is that barges determine (or update) their rotation during execution.

Table 1 Decision rules at different decision points

Decision node	**Decision**
Start	Solve a traveling salesman problem (minimizing the total sailing time) and head to the region of the first planned terminal
Choose terminal or leave region	Go to the terminal in this region with the lowest sum of the processing time of the waiting barges
Choose region	Go to the region of the first planned terminal, unless all terminals in the rotation are visited

6. SIMULATION MODEL AND EXPERIMENTAL SETTINGS

To evaluate the Multi-Agent System for different levels of information exchange, we consider different scenarios. To obtain insight in the functioning of the Multi-Agent System, we consider also other port configurations besides the Port of Rotterdam. In this section, we describe (briefly) the simulation model and the experimental settings. We use the same model and experimental settings as used in Douma et al. (2008).

6.1. Simulation model

For the simulator we apply an object oriented, discrete event simulation. The system we simulate comprises the terminals and barges. The course of the simulation is event based. This means that after an event the barge or terminal can perform an action resulting in a state transition, after which the state of the system remains unchanged until the next event. The state of the system can be described by the state of all the barges and terminals in the system. A barge can be in three states, namely sailing, waiting, or handling. A terminal can be in two states, namely handling a barge, or being idle. The state definitions might be augmented in the future with, e.g., handling sea vessels, closing of the terminal, et cetera. Events in our model are i) the arrival of a barge in the port, ii) the arrival of a barge at the terminal, iii) start handling, and iv) finish handling. Remark that these events only refer to a physical change in the system, arrival of information is not seen as an event. In the lowly cooperative case we have an additional event (related to the network of decision points), namely the arrival in a region. In the future also events (like a time trigger) related to the decision point *decide to keep waiting* might be introduced. On an event an action can be undertaken by a barge or a terminal. This requires a decision of either the barge operator or the terminal operator.

6.2. Experimental settings

This section describes the experimental settings. We assume that all handling and sailing times are deterministic. As time unit we use minutes in our experiments.

6.2.1. Scenarios

We have created 36 different scenarios varying along the dimensions presented in Table 2. Remark that the average utilization degree is input for the model, i.e., we generate the number of barges and terminal visits such that we obtain the desired utilization degree.

Table 2 Dimensions varied in the experiments

Variable	**Value**
Port layout	three variants (see Section 6.2.2)
Number of terminals per region	4 and 9
Number of quays per terminal	1
Utilization degree	50, 75, 90%
Time window barge	fixed, variable (see Section 6.2.4)

Every scenario is evaluated by means of simulations. For the waiting profile implementation, we also vary the value of the slack s (the additional flexibility in the waiting profile) for $s \in \{0,30,60\}$, with s in minutes.

All scenarios have a run length of 100 days. We apply a warm-up period of ten days (which proves to be sufficiently long) and a cool-down period of three days.

6.2.2. Network layouts

We consider three different port layouts (see Figure 2), which are inspired by the geographical structure of large ports around the world (Rotterdam (layout II), Antwerp (layout III), Hamburg (layout III), Singapore (layout II), and Shanghai (layout II)). We do not claim that our port layouts fit these ports exactly, but they are reasonable approximations. Layout I is added to evaluate the effect of regions on the performance of the system.

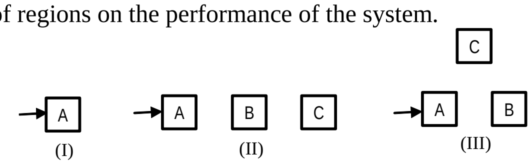

Figure 2 Three port layouts: one region, three regions in line, and three regions in a triangle. The arrows represent the port entrance and exit point.

We vary the number of terminals per region (either four or nine terminals). The sailing time between two terminals only depends on the regions each of the terminals belongs to, not on the Euclidian distance. In the port it is not possible to sail straight from one terminal to another, since there are only a few connecting water ways. We therefore assume that the sailing time within a region is always equal (we choose it to be 20 minutes). Sailing through a region (without visiting a terminal) takes 40 minutes. Sailing times between terminals are given by Table 3 on a regional level. So, for instance, from Table 3 we can see that traveling from a terminal in region A to a terminal in region C takes 240 minutes in a line port configuration.

Table 3 Sailing times (in minutes) between terminals belonging to specific regions

	Line			*Triangular*		
From/to a terminal in region	A	B	C	A	B	C
Port entrance and exit point	20	140	260	20	140	140
Region A	20	120	240	20	120	120
Region B	120	20	120	120	20	120
Region C	240	120	20	120	120	20

6.2.3. Parameter settings and distributions

The number of barges that visit the port within the planning horizon is derived from the number of terminals in the port, the number of quays per terminal, the average utilization degree, and the average number of terminal visits in a rotation. The inter-arrival time between barges is exponentially distributed.

Table 4 Parameter settings

Parameter	**Value**
Time to load or unload a container	3 min.
Mooring time on arrival and departure	10 min.
Maximum number of terminal visits per rotation	15

The call size (sum of the containers to load and unload) at a terminal is drawn from a normal distribution with mean 30 containers and a standard deviation of 10 containers. The handling time of a barge is the sum of the time to load and discharge containers, and the mooring time on arrival and departure. We discretize the normal distribution by rounding to the nearest integer with a minimum value of one. The number of terminal visits (calls) in a rotation is triangularly distributed with a minimum a, maximum b, and mode c. The mode denotes the most frequent value in the distribution. The minimum a is equal to one. The maximum b is equal to the maximum number of calls in a rotation or the number of terminals in the port. Mode c is equal to $(a+b)/2$. Other parameters are given in Table 4. We point out that the distributions used for the call size and the number of terminals in a rotation are inspired by real data.

6.2.4. Time window of the barge

Most barges, sailing the river Rhine to Rotterdam, sail according to sailing schedules that are determined once a year. Generally, this means that the total time a barge is supposed to be in the port is fixed, irrespective of the number of calls in the port, i.e., the time windows of all barges have equal length. However, due to disturbances and uncertain sojourn times in the port, one might argue that the sojourn times of barges in the port depend also on the number of terminal visits in the rotation. We therefore choose to consider both fixed and variable time windows.

Fixed time windows are determined as follows. We assume an average number of calls and an average call size per call. We assume that an average barge visits all regions in the port. Based on that, we can calculate the expected handling time (including mooring time) and sailing time. This is an estimate of the minimum time an average barge needs in the port to finish all its activities. To add slack for waiting at terminals, we multiply the sum of the handling and sailing time with some factor (1.8). This factor is chosen such that a reasonable number of barges can leave the port within their time window. The exact value of the factor is not very important in our experiments, more important is the fact that the time windows of all barges have the same length (in one single experiment). The size of the time window does not depend on the chosen average utilization degree.

The variable time windows are calculated as follows. For every barge, we calculate the sum of the handling time (including mooring time) and the expected sailing time. The result is increased with some fixed percentage of slack and a variable percentage depending on the number of terminals in the rotation. The slack per terminal is set to 4% and the fixed percentage depends on the utilization of the terminals and is for a utilization degree of 50, 75, and 90% equal to 10, 50, and 100%, respectively. So, for a barge that has to visit eight terminals in a port with a 50% utilization degree, this means that the time window is equal to total handling and sailing time in the rotation times 1+10%+8·4%=1.42.

7. RESULTS

In our experiments we assume that all terminals have the same degree of cooperativeness. In Section 7.1 we present the results of our simulation in case all terminals are fully cooperative. Section 7.2 gives these results in case all terminals are partly and lowly cooperative. In Section 7.3 we compare the performance of these three different degrees of cooperativeness.

7.1. The fully cooperative case

With respect to the results for the fully cooperative case we focus on an interesting relation between the *total waiting time* in a rotation and the *number of calls* (terminal visits) in a rotation, especially for utilization degrees of 75% and higher. In Figure 3 we depicted this relation based on ten replications of a scenario with port layout II, 9 terminals per region, and 90% utilization degree.

From the picture we can conclude the following. First, the waiting time reduces significantly if more slack is added to the waiting profile. Second, the total waiting time in a rotation reduces if a barge visits more terminals in its rotation. More specifically, the sum of the waiting and sailing time seems to be more or less constant in the number of terminals a barge visits (Figure 4).

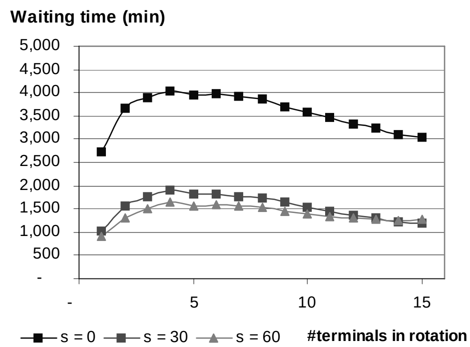

Figure 3 Average waiting times for different levels of slack and different rotation lengths in the fully cooperative case

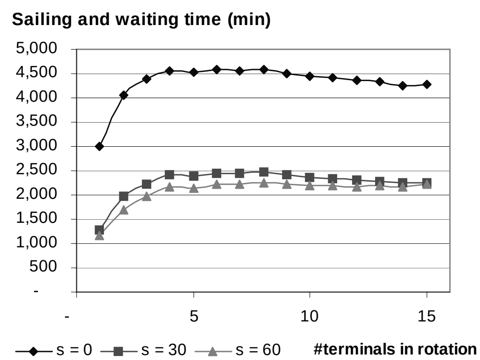

Figure 4 Average waiting and sailing times for different levels of slack and different rotation lengths in the fully cooperative case

This seems maybe counter intuitive. The explanation for this result is that barges, if they visit more terminals, use the waiting time at terminal A to visit another terminal B. Waiting time is then used party for sailing, handling and waiting at terminal B. Especially when a barge visits more terminals, it has more options to minimize its waiting time in a rotation.

7.2. The partly and lowly cooperative case

If we consider the relation between the total waiting time and the number of calls in a rotation for the partly or lowly cooperative case (for utilization degrees of more than 75%), we find that the total waiting time increases linearly with the number of terminals a barge has to visit. In Figure 5 we show this relation for the partly cooperative case, for the same scenario as used in Figure 3 and 4. The graph for the lowly cooperative case is similar except for the scale of the lines.

The reason that the total waiting time increases linearly is because terminals process barges FCFS. On every arrival at a terminal a barge has to enter the queue and wait for its service until all earlier arrived barges are processed.

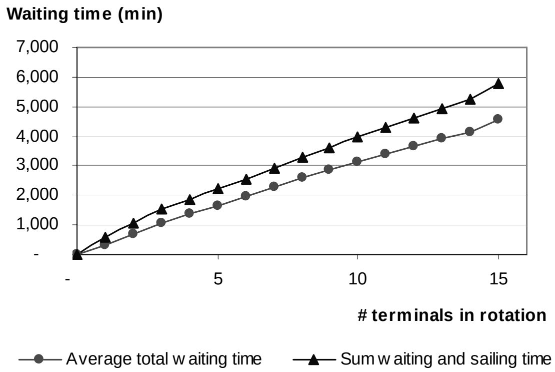

Figure 5 The waiting time, and the sum of the sailing and waiting time, if barges are processed FCFS

The difference in the partly and lowly cooperative case results mainly from the extent to which barges can use the information issued by terminals to reduce the average waiting time at a terminal, as can be seen in the next section.

7.3. Comparing the three degrees of cooperativeness

If we compare the average tardiness of barges for the different degrees of cooperativeness of terminals we find that being fully cooperative, with the use of waiting profiles including slack varying from 0-60 minutes, outperforms lower degrees of cooperativeness (see Figure 6 and 7).

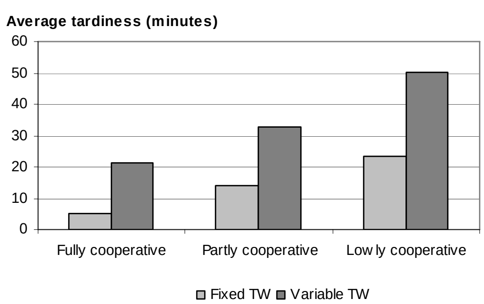

Figure 6 The average tardiness of barges averaged over all scenarios, specified for a 50% utilization degree and fixed and variable time windows

The reason why the partly cooperative situation performs worse for 90% utilization, is because barges determine a rotation (and announce the corresponding arrival times) based on the issued waiting profiles. This has some disadvantages. First, the waiting profiles might be outdated since barge arrivals can be significantly different from the announced arrival times. This effect is larger for higher utilization degrees. Second, barges assume that in the waiting time of one terminal another terminal can be visited. However, the waiting time at every terminal turns out be more or less equal.

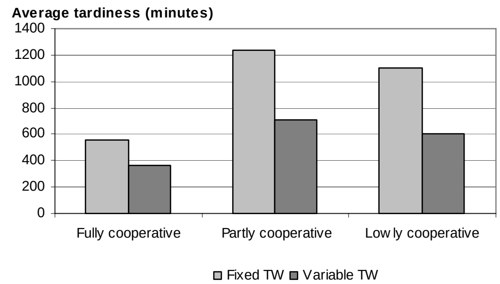

Figure 7 The average tardiness of barges averaged over all scenarios, specified for a 90% utilization degree and fixed and variable time windows

The fact that lowly cooperative outperforms partly cooperative – in case of a high utilization degree – is interesting from a barge perspective. This suggests that, if terminals are reluctant to provide any information to the barges, then barges will surely benefit from joining their forces and exchange information on a mutual basis.

Table 5 Average waiting time of a barge at terminal for different degrees of cooperativeness

Degree of cooperativeness	Avg. waiting time at terminal (min)
Fully	203
Partly	304
Lowly	294

If we consider the average waiting time of a barge at the terminal for the same scenario we used for Figure 3 and 4 (we averaged the results of all the terminals) we find the numbers presented in Table 5. The results of Table 5 compared with Figure 6 suggest that reduction of the average waiting time corresponds with a better performance in terms of average tardiness.

8. DISCUSSION AND CONCLUSIONS

Our simulation results suggest that the way terminals deal with barges influences to a large extent the performance of these barges. If terminals are fully cooperative there is more certainty about the barges that have to be processed, whereas in the lowly cooperative case terminals are not restricted by appointments and have more flexibility in their operations.

Although fully cooperative seems to be a good alternative, there is also a down-side for terminals. If terminals are fully cooperative, there is no real incentive for barges to reduce the number of terminals in a rotation. Reducing the number of terminal visits leads only to a small reduction of the port sojourn time. However, more terminal visits per barge means more dependencies between terminals, and on average smaller call sizes per barge resulting in more idle time of the crane during mooring of the barges. FCFS processing gives barges a clear incentive to reduce the number of terminal visits and is more robust against disruptions. However FCFS leads also to several disadvantages during operations. First, terminals do not exactly know when a barge is processed and when containers need to be stacked at the quay. Second, barge operators need to stow their barges very flexibly to be able to visit terminals in a different order. This affects the utilization degree of the barges. If barges make appointments, there is more certainty about their rotation, which enables them to increase their ship utilization. Third, there is more uncertainty in sojourn times of barges in the port, which makes the sailing schedules offered to carriers less reliable.

It is subject to discussion which degree of cooperativeness is desirable from both a terminal and barge perspective. If terminals are fully cooperative we expect that the balancing of the total workload over all terminals can be done more effectively than when terminals are less cooperative. This will generally result in shorter waiting times for barges at terminals such that more barges can depart the port timely. If terminals are partly cooperative, the value of waiting profiles might deteriorate dramatically, since terminals process barges at the time they prefer, but also barges might decide to visit terminals in a different sequence. Waiting profiles might then become misleading, since barges and terminals can act upon this information making it less relevant. If terminals are lowly cooperative, on the contrary, we expect that especially the introduction of sea vessels and opening times at terminals makes it hard to decide which terminal to visit when. Especially, like in Rotterdam, when barges visit several regions twice and they have the option to go to a terminal either the first time a region is visited or the second time.

We can imagine that in practice also a mix of degrees of cooperativeness can be found among terminals, for instance, terminals that participate in the Multi-Agent System (and are fully cooperative) and terminals that are not willing to participate. The latter terminals will cause a lot of uncertainties about the time a barge needs to be processed at those terminals, which makes it harder to make appointments with fully cooperative terminals. In this hybrid setting it is essential for barges that they make appointments such, that they can visit the less cooperative terminals in between the appointments.

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REFERENCES

Campbell, A. M., and Savelsbergh, M. (2006). Incentive schemes for attended home deliveries. *Transportation Science, 40*(3), 327-341.

Christiansen, M., Fagerholt, F., and Ronen, D. (2004). Ship Routing and Scheduling: Status and Perspectives. *Transportation Science, 38*(1), 1-18.

Connekt. (2003). *Eindrapport Approach*. Delft. Report is in Dutch: Connekt.

Cordeau, J. F., Laporte, G., Legato, P., and Moccia, L. (2005). Models and tabu search heuristics for the berh-allocation problem. *Transportation Science, 39*(4), 526-538.

Decker, K., and Li, J. (2000). Coordinating Mutually Exclusive Resources using GPGP. *Autonomous Agents and Multi-Agent Systems, 3*(2), 133-157.

Douma, A. M., Schutten, J. M. J., and Schuur, P. C. (2008). Waiting profiles: an efficient protocol for enabling distributed planning of barge rotations along terminals in the Port of Rotterdam. *To appear in Transportation Research Part C*.

Kraus, S. (1997). Negotiation and cooperation in multi agent environments. *Artificial Intelligence, 94*, 79-97.

Kumar, P., Kalwani, M.U., Dada, M. (1997). The impact of waiting time guarantees on customers' waiting experiences. *Marketing Science, 16*(4), 295-314.

Mailath, G. J., Samuelson, L. (2006). *Repeated Games and Reputations: Long-Run Relationships*: Oxford University Press.

Melis, M., Miller, I., Kentrop, M., van Eck, B., Leenaarts, M., Schut, M., et al. (2003). *Intelligent Logistics Concepts*.

Sandholm, T. (1999). Distributed Rational Decision Making. In *Multiagent Systems, A Modern Approach to Distributed Artifical Intelligence* (1 ed., pp. 201-258): MIT press.

Schut, M., Kentrop, M., Leenaarts, M., Melis, M., and Miller, I. (2004). APPROACH: Decentralised Rotation Planning for Container. *Proceedings of the 16th European Conference on Artificial Intelligence*.

Stahlbock, R., and Voss, S. (2008). Operations Research at Container Terminals: a literature update. *OR Spectrum, 30*, 1-52.

Steenken, D., Voß, S., and Stahlbock, R. (2004). Container terminal operation and operators research - a classification and literature review. *OR Spectrum, 26*, 3-49.

Whitt, W. (1999). Improving Service by Informing Customers about Anticipated Delays. *Management science, 45*(2), 192-207.

Wooldridge, M. J., and Jennings, N. R. (1995). Intelligent Agents: Theory and Practice. *The Knowledge Engineering Review, 10*(2), 115-152.